Review Article

Salicylic Acid Enhanced Low Temperature Stress Tolerance in Vegetables: A Review

Yogendra K Meena*[1] and Nirmaljit Kaur[2]

[1]Department of Vegetable Science, Punjab Agricultural University, Ludhiana-141004 (India)
[2]Department of Botany, Punjab Agricultural University, Ludhiana-141004 (India)

Abstract

Low temperature stress adversely affects growth, productivity and triggers a series of morphological, physiological and biochemical changes in plants. It is a major environmental cue that limits the vegetable productivity of plants, particularly in hilly areas. Development of procedures to enhance low temperature stress tolerance in plants is crucial and attracts considerable attention. The tolerance to low temperature stress is an intricate process that involves morphological, physiological and biochemical modifications. Salicylic acid is a vital signalling molecule for modulating plant response to various abiotic stresses. Salicylic acid induced alleviation of low temperature stress has been reported in vegetables. In this review, the aim is to emphasise the ameliorative effects of SA on growth, physiological, biochemical changes, yield and quality of plants growing under low temperature stress. On the basis of different studies, it has been concluded that SA enhanced the low temperature stress tolerance significantly and increased plant growth, photosynthetic pigments, accumulations of osmoprotectants and activity of antioxidant enzymes. It also increased production and quality of vegetables under low temperature stress.

Keywords: Photosnthetic pigments, osmoprotectants, antioxidant enzyme, growth, yield and quality

***Correspondence**
Author: Yogendra K Meena
Email: yogendra-coavs@pau.edu

Introduction

Environmental stress such as cold, heat, salinity and drought adversely affect growth and productivity and trigger a series of morphological, physiological, biochemical and molecular changes in plants that eventually interrupt plant life [1, 2]. Most of the arable lands of world, which when exposed to these abiotic stress conditions have an adverse impact on global vegetables production. These abiotic stress conditions decrease crop productivity upto 50-70% [3]. Plants undergo several metabolic cascades for their survival during these stress conditions [4]. Plant's response is a complex phenotypic and physiological phenomena which is highly influenced by low temperature stress. To enhance the food production, crops are often grown under stressful environments which result in lower yield. The key factors to reduce yield and quality of crops are fluctuations in climatic conditions, such as low temperature stress. During winter season, low temperature stress adversely damages vegetable production. In response to low temperature stress, several phenotypic symptoms such as stunted seedling, poor germination, reduced leaf expansion, yellowing of leaf (Chlorosis) and wilting occur, which sometimes results into tissue damage (necrosis) [5].

Vegetables have an imperative role to play in the diversification of agriculture. They ensure food and nutritional security of the ever budding population of India. However, vegetables are sensitive crops and their production is hindered by various abiotic stresses. Temperature, both low and high, is the most serious environmental stresses. Low temperature stress has been reported as one of the most restraining environmental factors for agricultural crops, particularly vegetables, which accounts for significant crop losses [6]. Summer vegetables are sensitive to chilling temperature (0-15°C) throughout plant development *i.e.* seed germination, vegetative growth and reproduction. Under low temperatures, lots of seeds do not germinate or germinate irregularly and plants grow differentially with delayed plant formation leading to variability in crop development. During later stages, plant growth and development are extremely retarded that either limit or lead to no flower and fruit production [7]. Numerous factors affect the degree of injury which may be temperature, time of exposure, organ or tissues of the plant exposed and the physiological stage and temperature at which the plant is being grown [8]. Weak fruit set after a cold period could be due to the poor pollen viability [9]. Chilling sensitivity can occur at two distinct developmental stages i.e., pollen formation (from meiosis to release of mature pollen) and pollen function [10]. Low temperature stress affects the reproductive stages of plant with delayed flowering which makes the pollen sterile that severely affects the crop yield [6, 11]. Low temperature stress also limits the agricultural productivity of plants in hilly areas and has a major impact on the survival and geographical distribution of the plants. The plant growth and crop productivity gets disturbed which results in substantial crop failure [12].

Plant hormones have an essential role to play in regulating the developmental processes and signaling network in plants suffering from abiotic stress. Recent studies have shown that plant hormones have potent role in reducing or eliminating the adverse effects of abiotic stress [13, 14]. Recently, salicylic acid (SA) has been added to the existing list of classical phytohormones and is considered as a possible tool to boost tolerance in plants to environmental stress. Salicylic acid is an endogenous plant growth regulator and reportedly has a wide range of metabolic and physiological responses that affect the growth and development of plants [15]. SA, an active phenolic compound plays an important role in providing resistance to plants against pathogens. It takes part in the defense mechanism of plants in response to abiotic stresses such as low and high temperature stress [16-18]. SA is a plant hormone which plays a crucial role in the regulation of physiological and molecular mechanisms to acclimatise plants in extreme environmental conditions and is believed to have a role in plant's response to abiotic stress [16, 17, 19, 20]. SA and other phenolic compounds (benzoic acid, acetyl SA, SSA) have been found to increase cold tolerance of plants when applied exogenously [16, 21].

Development of methods to enhance stress tolerance in plants is crucial and attracts considerable attention. The tolerance to cold stress is an intricate process that involves morphological, physiological and biochemical modifications. Salicylic acid is a vital signal molecule for modulating plant response to various abiotic stresses [15]. Salicylic acid induced alleviation of cold stress has been reported in tomato [21-23], cucumber [24], squash [25] and watermelon [26]. In this review, the ameliorative effects of SA on growth, physiological, biochemical changes, yield and quality of plants growing under low temperature conditions have been discussed.

Amelioration of Low Temperature Stress

Use of plant growth regulators (PGRs) to induce low temperature stress tolerance in pants is one of the possible approach. In recent studies, several PGRs have been tested to alleviate the low temperature stress in plants [22, 23, 27, 28]. Salicylic acid (SA) is a plant produced phenolic compound that can function as a PGR. Its an endogenous plant growth regulator and has been found to generate a wide range of metabolic and physiological responses in plants affecting their growth and development [15]. SA has received much attention due to its major functions in plant's responses to biotic and abiotic stresses. Several studies have been reported about various beneficial effects of SA on plants under abiotic stresses [18, 29]. Sayyari [26] reported that foliar application of SA increased cold tolerance of cucumber. In tomato and bean plants, the lower concentration of SA and ASA (acetyl salicylic acid) @ 0.1 mM and 0.5 mM have been found more effective against low temperature stress [22, 30]. ASA is a close analogue of SA and when applied exogenously is converted to SA spontaneously, having similar effects to SA in plant defense processes [31-33]. Orabi [22] reported that SA led to enhancement of endogenous growth regulators under low temperature. SA enhanced plant growth and cell division via regulation of other hormones [34] and mitigating abiotic stresses by increasing the growth regulating hormones like auxins and cytokinins [35]. Moreover, the application of SA increases the content of auxin and ABA and prevents the reduction of cytokinin under drought and salinity stress conditions thereby producing a higher total biomass and seed vigor index[35, 36].

Plant Growth and Development

Salicylic acid is a natural phenolic compound that plays the role of a key signaling molecule in induction of plant defense mechanism and reduces symptoms of abiotic stress as well as regulates growth and development of plants [16, 18]. Low concentration of SA enhances and influences the differentiation of cells, tissues of plants and increases the plant growth and development [37]. The enhanced fresh and dry matter of plants under stress conditions in response to SA might be related to the increase of antioxidant response that enhances the tolerance of plants to damage by environmental stress [38-40]. Exogenous application of SA enhanced the activity of cell division by stimulating the mitosis of the apical meristem of seedling roots which caused an improvement in plant growth and deve lopment [41]. Application of SA under low temperature stress significantly increased the growth attributes viz., plant height, number of leaves per plant, fresh and dry weights of leaves and root length in tomato [21, 22]. Similar results obtained by Sayyari [26] in watermelon and Imami [42] in chickpea showed that the growth parameters increased significantly with the application of SA under cold stress. The ability of SA to enhance growth parameters, ameliorating the adverse effects of low temperature stress, may have significant implications in increasing the plant growth and development, and overcoming the growth barrier. Gharib [43] reported that enhanced photosynthetic activity in basil with the application SA at low concentration enhanced plant growth attributes *viz.*, plant height, number of branches and leaves per plant as well as leaf area, fresh and dry weights. Similar there are reports that application of SA significantly enhanced growth parameters such as; length and dry weight of root and shoot, leaf area, specific leaf area, specific leaf weight and leaf weight ratio under stress conditions [44-47]. Application of SA increased photosynthetic rate due to increased leaf area as has been reported by Gharib [43]. Hussein [48] and Hayat [10] also reported increased productivity due to an improvement in all growth attributes including plant height, number of leaves, leaf area, dry and fresh weight of shoot, leaves and plant with the application of SA under stress condition. Fariduddin [49] observed that the dry biomass per plant increased significantly with the application of low concentration of SA. However, application of higher concentrations of SA had an inhibitory effect on dry biomass under stress [15].

Physiological and Biochemical Mechanisms

Plant species have developed various physiological and biochemical mechanisms to cope with abiotic stresses. For instance, to mitigate low temperatures stress induced damage, plants may up regulate different scavenging mechanisms, such as enzymatic antioxidants catalase (CAT), ascorbate peroxidase (APX) and peroxidase (POD) and osmoprotectants (stress signaling substance) [50, 51]. These compounds protect membranes and photosynthetic apparatus from the injurious effects caused by abiotic stresses [52, 53]. Phenolic compounds are common plant produced signaling molecules responsible for enhanced tolerance to environment stresses [54]. SA acts as a cofactor for various enzymes and regulates the phytohormone mediating signaling processes and many physiological and biochemical processes in plants. SA is a vital signaling molecule in plants which defends the plant from various abiotic stresses like cold stress [50, 51, 55].

Several studies reported that SA is a crucial regulator of photosynthesis because it affects chloroplast and leaf structure, stomatal closure, chlorophyll and carotenoid contents [49]. Application of SA enhanced the photosynthetic net CO_2 assimilation in mustard seedlings. The role of SA at a certain stage with moderate and grievous environment stress may be a part and can be attributed to redox regulations in plant cells and protection of the cell structure under low temperature stress [56, 57]. SA plays crucial roles in response to external stimulation and by activating defense system in plants. Activation of phospholipase D is an early response to low temperature, involved in the accumulation of free SA and the development of thermotolerance induced by low temperature acclimation in grape berries [58]. SA acts as an endogenousphytohormone from phenolic compound family, having the capacity of antioxidant protection system and regulates different physiological and biochemical processes in plant such as: activity of photosynthesis pigments, maintenance of tissue water contents and reduced membrane permeability, adjustment of the activity of antioxidant enzymes, stomatal conductivity and tolerance to various abiotic stresses [15, 36, 50, 59]. Furthermore, SA treatment maintains IAA and cytokinin levels in the plant tissues, which enhance the cell division and dry weight as reported by Sakhabutdinova [41]. Miura and Tada [18] observed that the effects of SA on the physiological and biochemical processes of plants depend on the concentration and period of application, type of plant, the stage of growth and environmental conditions [22]. Several workers have reported that low concentration of SA may increase the activation of antioxidants [50] and tolerance to various abiotic stresses, similar reports have been made by Senaratna [30] that treatment at low concentrations of (0.1 and 0.5 mM) promoted tolerance to chilling stress in bean and tomato. But high concentrations of SA may cause negative results or susceptibility to abiotic stresses [60]. The exogenous application of SA (0.5 mM) enhanced the low temperature stress tolerance of cucumber [61] and potato [62]. Similarly, Kang [63] reported that the foliar application of SA @0.5mM on the leaves of banana enhanced the chilling tolerance.

Regarding SA effect, Khodary [38] and Szepesi [64] reported that application of SA enhanced the photosynthetic pigments (chlorophyll, carotenoid contents), increased the photosynthetic efficiency, photosynthetic rate, dry weights and reduced the membrane leakage, leading to increased plant growth in tomato plants under stress conditions. Similarly, Shi [65] noticed that exogenous application of SA significantly increased net photosynthetic rate which could be due to the improvement in the functioning of photosynthetic machinery in plants either by the mobilization of internal tissue nitrate or by chlorophyll biosynthesis. Suitable concentrations of SA and ASA inhibit chlorophyll degradation and enhanced photosynthesis by prohibition of chlorophyll oxidase enzyme activity in tomato [15, 22, 23, 66]. Environmental stresses enhance injures of cellular membrane including the increased electrolyte leakage MDA and H_2O_2 content due to oxidative damage and they are considered to be sensitive stress markers [22, 23, 67, 68]. However, several workers have reported that the decrease of electrolyte leakage, MDA and H_2O_2 content in tomato with the application of SA and also mentioned that foliar application of SA regulates and maintains the membrane functions of tomato plants[22, 40, 69]. Further, SA and ASA can curtail the injuries in cell membranes through increased antioxidant enzyme activity of plants under several abiotic stress conditions and partly maintain membrane permeability as well as reduce the amount of electrolyte leakage [22, 61, 70]. Similarly, Kabiri [71] and Orabi [22] reported that application of SA increased the reduction in the level of lipid peroxidation and electrolyte leakage from leaves as well as with more profound growth processes as compared to non stress plants of tomato.

Stressful environments induce the generation of reactive oxygen species (ROS) such as hydrogen peroxide (H_2O_2), superoxide radicals (O_2^-), hydroxyl radicals (OH^-) *etc*. in plants thereby indicate a state of oxidative stress [72]. This enhanced ROS level in plants suggest oxidative damage to biomolecules such as lipids, proteins and nucleic acids, thus altering the redox homeostasis [73]. However, Kang [63] reported that SA increased the efficiency of antioxidant system in plants under stress conditions. SA treatments caused marked decrease in CAT activity accompanied by significant enhancement in the activities of POD and APX relative to control plants in fresh leaf and root tissues of tomato under low temperature conditions. The reduction in CAT activity and enhancement in POD and APX activities were more pronounced in response to applications of SA in tomato [22]. Foliar application of SA could regulate the synthesis and activities of antioxidant enzymes and enhance plant tolerance to abiotic stress [74]. Hayat [15] reported significantly enhanced activities of antioxidant enzymes such as POD, CAT and APX with the application of SA to stressed plants [75] which might be due to its regulatory function at transcriptional or translational level. Similarly, Yusuf [76] and Boukraa [77] found that application of SA enhanced the level of antioxidant enzymes such as (CAT, POD, APX and SOD) under stress conditions. Gharib and Hegazi [78] reported that the CAT, POD, APX and SOD may be coordinately regulated during plant growth and development, but differentially expressed in response to various abiotic stresses for controlling ROS homeostasis [79]. SA enhanced low temperature stress tolerance to watermelon by increasing the activities of POD, CAT, APX and SOD. The activities of antioxidative enzymes enhanced significantly in the low temperature stress tolerant watermelon germplasm than that of the cold stress sensitive germplasm [80, 81].

Yield and Quality

Low temperature stress significantly decreases the yield and quality of vegetables. Application of SA enhanced yield and quality of tomato under low temperature stress conditions [21, 22]. Similar reports have been made in cucumber [82]. Number of fruits significantly enhanced in pepper [15] and cucumber [83] in response to foliar application of SA. Several studies revealed that application of phenolic compounds were able to reduce chilling symptoms in tomato fruits [84]. Javaheri [85] reported that the application of SA significantly enhanced the amount of vitamin C, lycopene and also increased rate of pressure tolerance of fruits, improved quantity and quality of tomato fruits. Recent studies suggest the predominant role of the phenolic compounds in the modulation of the response of plants towards environmental stresses by induction of the antioxidant ability [22, 77]. Exogenous application of SA alleviated the toxic action induced by low temperature and decreased lipid peroxidation rates with increasing antioxidant activity. Chandra [86] reported that exogenous application of SA enhanced total soluble sugar and soluble protein of cowpea plants. Khandaker [46] reported that the foliar application of SA in red amaranth significantly enhanced the yield, antioxidant activity, amount of beta-cyanins, chlorophyll and total polyphenols. The application of SA treatments (0.5 mM and 1.0 mM) caused significant increase in Total Soluble Solids (TSS) in fruits of tomato [22]. TSS values are associated with taste and have significant indication for improvement in yield and quality. Moreover, Abdullahi [87] showed that plant growth and TSS levels increased after application of salicylic acid.

Conclusion

Vegetables have an imperative role to play in the diversification of agriculture. They ensure food and nutritional security of the ever budding population of India. However, vegetables are sensitive crops and their production is hindered by various abiotic stresses. Temperature, both low and high, is the most serious environmental stresses. Low temperature stress has been reported as one of the most restraining environmental factors for agricultural crops, particularly vegetables, which accounts for significant crop losses. Low temperature stress adversely affects growth, productivity and triggers a series of morphological, physiological and biochemical changes in plants. It is a major environmental cue that limits the vegetable productivity. The demand for food and vegetables will continue to rise with the increase in global population; therefore improving productivity to ensure sustainable yields under changing environmental conditions is imperative. Development of methods to enhance stress tolerance in plants is crucial and need based. The tolerance to cold stress is an intricate process that involves morphological, physiological and biochemical modifications. SA, an active phenolic compound plays an important role in providing resistance to plants against pathogens and in response to abiotic stresses such as low and high temperature stress. SA plays a significant role in the regulation of physiological and molecular mechanisms to acclimatise plants in extreme environmental conditions and is believed to have a role in plant's response to abiotic stress

References

[1] Mahajan S and Tuteja N (2005) Cold, salinity and drought stresses: an overview. Arch Biochem Biophys 444(2): 139-58.

[2] Ahmad P and M N V Prasad (2012) Abiotic stress responses in plants: metabolism, productivity and sustainability, Springer, New York, NY, USA.

[3] Miller G, Shulaev V and Mittler R (2008) Reactive oxygen signaling and abiotic stress. Physiol Plant 133: 481-89.

[4] Dos Reis, S P, Lima A M, and De Souza C R B (2012) Recent molecular advances on downstream plant responses to abiotic stress. Int J Mol Sci 13: 8628-47.

[5] Ruelland E and Zachowski A (2010) How plants sense temperature. Environ Exp Bot 69: 225-32.

[6] Yadav S (2010) Cold stress tolerance mechanisms in plants. A review. Agron Sustain Dev 30: 515-27.

[7] Foolad M R and Lin G Y (2000) Relationship between cold tolerance during seed germination and vegetative growth in tomato: germplasm evaluation. J Amer Soc Hort Sci 125(6): 679-83.

[8] Vallejos C E (1979) Genetic diversity of plants for response to low temperature and its potential use in crop plants, p. 473-489. In: J.M. Lyons, D. Graham, and J.K. Raison (eds.). Low-temperature stress in crop plants. Academic Press, New York.

[9] Charles W B and Harris R E (1972) Tomato fruit-set at high and low temperatures. Can J Plant Sci 52: 497-506.

[10] Zamir D, Tanksley S D and Jones RA (1982) Haploid selection for low temperature tolerance of tomato pollen. Genetics 101:129-37.

[11] Suzuki K, Nagasuga K and Okada M (2008) The chilling injury induced by high root temperature in the leaves of rice seedlings. Plant Cell Physiol 49: 433-42.

[12] Xin Z and Browse J (2001) Cold comfort farm: the acclimation of plants to freezing temperatures. Plant Cell Environ 23: 893-902.

[13] Yoon J Y, Hamayun M, Lee S K and Lee I J (2009) Methyl jasmonate alleviated salinity stress in soybean. J Crop Sci Biotechnol 12: 63-68.

[14] Gémes K, Poór P, Horváth E, Kolbert Z, Szopkó D, Szepesi Á and Tari I (2011) Cross-talk between salicylic acid and NaCl-generated reactive oxygen species and nitric oxide in tomato during acclimation to high salinity. Physiol Plant 142: 179-92.

[15] Hayat Q, Hayat S, Irfan M and Ahmad A (2010) Effect of exogenous salicylic acid under changing environment: A review. Environ Experi Bot 68: 14-25.

[16] Horváth E, Szalai G, Pál M, Páldi E and Janda T (2007) Differences between the catalase isozymes of maize (Zea mays L.) in respect of inhibition by various phenolic compounds. Acta Biol Szegediensis 46: 33-34.

[17] Yuan S and Lin H H (2008) Role of salicylic acid in plant abiotic stress. Zeitschrift fur Naturforschung C 63: 313-20.

[18] Miura K and Tada Y Y (2014) Regulation of water, salinity and cold stress responses by salicylic acid. Plant Physiol 5: 1-12

[19] Bari R and Jones J D G (2009) Role of plant hormones in plant defense response. Plant Mol Biol 69: 473-88.

[20] Okrent R A, Brooks M D and Wildermuth M C (2009) Arabidopsis GH3.12 (PBS3) conjugates amino acids to 4-substituted benzoates and is inhibited by salicylate. J Biol Chem 284: 9742-54.

[21] Meena Y K, D S Khurana, Nirmaljit Kaur and Kulbir Singh (2017) Phenolic compounds enhanced low temperature stress tolerance in tomato (Solanum lycopersicum L.). British Journal of Applied Science & Technology 20(3)1-9

[22] Orabi S A, Dawood M G and Saleem S R (2015) Comparative study between the physiological role of hydrogen peroxide and salicylic acid in alleviating low temperature stress on tomato plants grown under sand-ponic culture. Sci Agric 9(1): 49-59.

[23] Khan T A, Fariduddin Q and Yusuf M (2015) Lycopersicon esculentum under low temperature stress: an approach toward enhanced antioxidants and yield. Environ Sci Pollut Res DOI 10.1007/s11356-015-4658-5

[24] Zhang Y, Chen K, Zhang S and Ferguson I (2003) The role of salicylic acid in postharvest ripening of kiwifruit. Postharvest Biol Technol 28: 67-74.

[25] Mady M A (2014) Inducing cold tolerability in squash (Cucurbita pepo l.) Plant by using salicylic acid and chelated calcium application. Int J Agri Sci Res 4(4) 9-14.

[26] Sayyari M, Ghanbari F, Fatahi S and Bavandpour F (2013) Chilling tolerance improving of watermelon seedling by salicylic acid seed and foliar application. Not Sci Biol 1: 67-73.

[27] Balestrasse K B, Tomaro M L, Battle A and Noriega G O (2010) The role of 5-aminolevolinic acid in the response of cold stress in soybean plants. Phytochem 71: 2038-45.
[28] Korkmaz A, Korkmaz Y and Demirkiran A R (2010) Enhancing chilling stress tolerance of pepper seedling by exogenous application of 5- aminolevolinic acid. Environ Exp Bot 67: 495-501.
[29] Pál M, Kovács V, Szalai G, Soós V, Ma X and Liu H et al (2014) Salicylic acid and abiotic stress responses in rice. J Agro Crop Sci 200: 1-11.
[30] Senaratna T, Merritt D, Dixon K, Bunn E, Touchell D and Sivasithamparam K (2003) Benzoic acid may act as the functional group in salicylic acid and derivatives in the induction of multiple stress tolerance in plants. Plant Growth Regul 39: 77-81.
[31] Beckers G J M and Spoel S H (2006) Fine-tuning plant defense signalling: salicylate versus jasmonate. Plant Biol 8: 1-10.
[32] Hayat S, Ali B and Ahmad A (2007) Salicylic acid- Plant hormone, Springer, Dordrecht, The Netherlands.
[33] Scotter M J, Roberts D P T, Wilson L A, Howard F A C, Davis J and Mansell N (2007) Free salicylic acid and acetyl salicylic acid content of foods using gas chromatography–mass spectrometry. Food Chem 105: 273-79.
[34] Zarghami M, Shoor M, Ganjali A, Moshtaghi N and Tehranifar A (2014) Effect of salicylic acid on morphological and ornamental characteristics of petunia hybrida at drought stress. Ind J Fund Appl Life Sci 4: 523-32.
[35] Shakirova F M, Sakhabutdinova A R, Bezrukova M V, Fatkhutdinova R A and Fatkhutdinova D R (2003) Changes in the hormonal status of wheat seedlings induced by salicylic acid and salinity. Plant Sci 164: 317-22.
[36] Kabiri R, Farahbakhsh H and Nasibi F (2012) Effect of drought and its interaction with salicylic acid on black cumin germination and seedling growth. World Appl Sci J 18: 520-27.
[37] Helgi Öpik S and Rolfe A (2005) The physiology of flowering plants. pp. 191 Cambridge University Press Plant Physiology
[38] Khodary S E A (2004) Effect of salicylic acid on the growth, photosynthesis and carbohydrate metabolism in salt stressed maize plants. Int J Agric Biol 6:5–8.
[39] Gunes A, Inal A, Alpaslan M, Cicek N, Guneri E, Eraslan F and Guzelordu T (2005) Effects of exogenously applied salicylic acid on the induction of multiple stress tolerance and mineral nutrition in maize (Zea mays L.). Arch Agron Soil Sci 51: 687-95.
[40] Stevens J, Senaratna T and Sivasithamparam K (2006) Salicylic acid induces salinity tolerance in tomato (Lycopersicon esculentum cv. Roma): associated changes in gas exchange, water relations and membrane stabilisation. Plant Growth Regul 49: 77-83.
[41] Sakhabutdinova A R, Fatkhutdinova D R, Bezrukova M V and Shakirova F M (2003) Salicylic acid prevents the damaging action of stress factors on wheat plants. Bulg J Plant Physiol special issue: 314-19.
[42] Imami S, Jamshidi S and Shahrokhi S (2011) Salicylic acid foliar and soil application effect on chickpea resistance to chilling stress. International Conference on Biology, Environment and Chemistry. IPCBEE vol. 24. IACSIT Press, Singa- poore.
[43] Gharib F A (2006) Effect of salicylic acid on the growth, metabolic activities and oil content of basil and marjoram. Int J Agr Biol 4: 485-92.
[44] Cornelia P, Petrus A, Pop L, Chis A and Bandici G E (2010) Exogenous salicylic acid involvement on some physiological parameters amelioration in salt stressed wheat (Triticum aestivum) plantlets. Analele Universitatii din Oradea, Fascicula: Protectia Mediului. 15: 160-65.
[45] BoroumandJazi S, Lariyazdi H and Ranjbar M (2011) Effect of salicylic acid on some plant growth parameters under lead stress in Brassica napus var. Okapi. Int J Plant Physiol 1(3): 117- 85.
[46] Khandaker L, Masumakond A S M G and Oba S (2011) Foliar application of salicylic acid improved the growth, yield and leaves bioactive compounds in Red Amaranth (Amaranthus tricolor L.). Veg Crops Res Bulletin 74: 77-86.
[47] Zamaninejad M, Khavari Khorasani S, Jami Moeini M and Heidarian A R (2013) Effect of salicylic acid on morphological characteristics, yield and yield components of corn (Zea mays L.) under drought condition. European J Exp Biol 3(2): 153-61.
[48] Hussein M M, Balbaa L K and Gaballah M S (2007) Salicylic acid and salinity effects on growth of maize plants. Res J Agric Biol Sci 3(4): 321-28.
[49] Fariduddin Q, S Hayat and Ahmad A (2003) Salicylic acid influences net photosynthetic rate, carboxylation efficiency, nitrate reductase activity and seed yield in Brassica juncea. Photosynthetica 41: 281-84.
[50] Farooq M, Aziz T, Basra S M A, Cheema M A and Rehman H (2008) Chilling tolerance in hybrid maize induced by seed priming with salicylic acid. J Agrono Crop Sci 194 (2): 161-68.

[51] Ahmad I, Basra S M A, Afzal I, Farooq M and Wahid A (2013) Growth improvement in spring maize through exogenous application of ascorbic acid, salicylic acid and hydrogen peroxide. Int J Agric Biol 15: 95-100.
[52] Foyer C and Noctor G (2003) Redox sensing and signalling associated with reactive oxygen in chloroplasts, peroxisomes and mitochondria. Physiol Plant 11: 355-64.
[53] Gautam S and Singh P K (2009) Salicylic acid-induced salinity tolerance in corn grown under NaCl stress. Acta Physiol Plant 31:1185-90.
[54] Karlidag H, Yildirim E and Turan M (2009) Exogenous applications of salicylic acid affect quality and yield of strawberry grown under antifrost heated greenhouse conditions. J Plant Nut Soil Sci 172 (2): 270-76.
[55] Chen Z, Zheng Z, Huang J, Lai Z and Fan B (2009) Biosynthesis of salicylic acid in plants. Plant Signal Behav 4: 493-96.
[56] Zhang K G, Xun W Z, Fei X K and Chou S G (2007) Protection of ultra structure in chilling- stressed banana leaves by salicylic acid. J Zhejiang Uni (Science B) 8(4): 277-82.
[57] Shu Y and Hui H L (2008) Role of salicylic acid in plant abiotic stress. Biosciences 63(5/6): 313-20.
[58] Bao W S, Tian L, Rong T R, Hong P Q, Cheng Z J, Fei W P, Ye C J, Ping Z, Wei W and H W Dong (2009) Involvement of phospholipase-D in the low temperature acclimation-induced thermotolerance in grape berry. Plant Physiol Biochem 47(6): 504-10.
[59] Carvalho R F, Piotto F A, Schmidt D, Peters L P, Monterio C C and Azevedo R A (2011) Seed priming with hormones dose not alleviate induced oxidative stress in maize seedling subjected to salt stress. Sci Agric 68: 598-602.
[60] Hara M, Furukawa J, Sato A, Mizoguchi T and Miura K (2012) Abiotic stress and role of salicylic acid in plants. 235-251. Eds A Parvaiza and M NV Prasad Abiotic Stress Responses in Plants. New York, NY: Springer.
[61] Kang H M and Saltveit M E (2002) Chilling tolerance of maize, cucumber and rice seedling leaves and roots are differentially affected by salicylic acid. Physiol Plant 115: 571–76.
[62] Mora-Herrera M E, López-Delgado H, Castillo-Morales A and Foyer C H (2005) Salicylic acid and H2O2 function by independent pathways in the induction of freezing tolerance in potato. Physiol Plant 125: 430-40.
[63] Kang G Z, Wang Z X and Sun G C (2003) Participation of H2O2 in enhancement of cold chilling by sali- cylic acid in banana seedlings. Acta Bot Sin 45: 567-73.
[64] Szepesi A (2006) Salicylic acid improves the acclimation of Lycopersicon esculentum Mill. L. to high salinity by approximating its salt stress response to that of the wild species L. Pennellii. Acta Biol Szeged 50 (3-4): 177.
[65] Shi Q, Bao Z, Zhu Z, Ying Q and Qian Q (2006) Effect of different treatments of salicylic acid on heat tolerance, chlorophyll fluorescence, and antioxidant enzyme activity in seedlings of Cucumis sativa L. Plant Growth Regul 48: 127-35.
[66] Belkhadi A, Hediji H, Abbes Z, Nouairi I, Barhoumi Z, Zarrouk M, Chaibi W and Djebali W (2010) Effects of exogenous salicylic acid pre-treatment on cadmium toxicity and leaf lipid content in Linum usitatissimum L. Ecotox Environ Safe 73: 1004-11.
[67] Moskova I, Todorova D, Alexieva V, Ivanov S and Sergiev I (2009) Effect of exogenous hydrogen peroxide on enzymatic and non-enzymatic antioxidants in leaves of young pea plants treated with paraquat. Plant Growth Regul 57: 193-202.
[68] He L, Gao Z, and Li R (2009) Pretreatment of seed with H2O2 enhances drought tolerance of wheat (Triticum aestivum L.) seedlings. Afri J Biotech 8: 6151-57.
[69] Agamy R A, Hafez E E and Taha T H (2013) Acquired resistant motivated by salicylic acid applications on salt stressed tomato (Lycopersicon esculentum Mill.). American Eurasian J Agric Environ Sci 13(1): 50-7.
[70] Tasgin E, Okkes A, Nalbantoglu B and Popova L P (2006) Effects of salicylic acid and cold treatments on protein levels and on the activities of antioxidant enzymes in the apoplast of winter wheat leaves. Phytochem 67: 710-15.
[71] Kabiri R, Nasibi F and Farahbakhsh H (2014) Effect of Exogenous salicylic acid on some physiological parameters and alleviation of drought stress in Nigella sativa plant under hydroponic culture. Plant Protect Sci 50: 43-51.
[72] Panda S K, Chaudhury I and Khan M H (2003) Heavy metal induced lipid peroxidation and affects antioxidants in wheat leaves. Biol Plant 46: 289-94.
[73] Gille G and Singler K (1995) Oxidative stress in living cells. Folia Microbiol 2: 131-52.
[74] Fayez K A and Bazaid S A (2014) Improving drought and salinity tolerance in barley by application of salicylic acid and potassium nitrate. J Saudi Soc Agric Sci 13: 45-55.

[75] Szepesi A, Poor P, Gemes K, Horvath E and Tari I (2008) Influence of exogenous salicylic acid on antioxidant enzyme activities in roots of salt stressed tomato plants. Acta Biol Szeged 52: 199-200.

[76] Yusuf M, Fariduddin Q, Varshney P and Ahmad A (2012) Salicylic acid minimizes nickel and/or salinity-induced toxicity in Indian mustard (Brassica juncea) through an improved antioxidant system. Environ Sci Pollut Res 19: 8-18.

[77] Boukraa D, Belabid L, Benabdelli K and Bennabi F (2014) The effect of the salicylic acid on the variability of phenolic compounds, during the germination and the seedling of chickpea (Cicer arietinum L.), after inoculation by mushrooms. Eur J Biotechn Biosci 1: 27-35.

[78] Gharib F A and Hegazi A Z (2010) Salicylic acid ameliorates germination, seedling growth, phytohormone and enzyme activity in bean (Phaseolus vulgaris L.) under cold stress. J Amer Sci 6: 675-83.

[79] Yang Jing-Hua, Yuana G, Yan-Mana L ,Xiao-Hua Q and Ming-Fanga Z (2008) Salicylic acid-induced enhancement of cold tolerance through activation of antioxidative capacity in watermelon. Sci Hort 118: 200-05.

[80] El-Bahy M M (2002) Metabolic changes, phytohormonal level and activities of certain related enzymes associated with growth of presoaked lupine seeds in salicylic and gallic acid. Bul. Fac Sci Assuit Univ 31: 259-70.

[81] Hua Y J, Yuan G, Man L Y, Hua Q X and Fang Z M (2008) Salicylic acid-induced enhancement of cold tolerance through activation of antioxidative capacity in watermelon. Scientia Hort 118 (3): 200-05.

[82] Larque-Saavedra A and Martin-Mex R (2007) Effect of salicylic Acid on the bioproductivity of plant 2:15-23. Hayat S, Ahmad A (Eds). Salicylic Acid: A Plant Hormone. Springer. Dordrecht. Netherlands.

[83] Elvwan M W M and Hamahyomy M A M (2009) Improved productivity and quality associated with Salicylic acid application in greenhouse pepper. Sci Hortic 122: 521-26.

[84] Aghdam M S, Asghari M R, Moradbeygi H, Mohammadkhani N, Mohayeji M and Rezapour-Fard J (2012) Effect of postharvest salicylic acid treatment on reducing chilling injury in tomato fruit. Rom Biotechnol Lett 17: 7466-73.

[85] Javaheri M, Mashayekhi K, Dedham A and Zaker- Tavallaee F (2012) Effects of salicylic acid on yield and quality characters of tomato fruit (Lycopersicon esculentum Mill.). Intl J Agric Crop Sci 4: 1184-87.

[86] Chandra A, Anand A and Dubey A (2007) Effect of salicylic acid on morphological and biochemical attributes in cowpea. J Environ Biol 28:193-96.

[87] Abdullahi M, Jafarpour M and Zeinali H (2011) Effect of various salicylic acid concentrations on growth of Aloe vera L. Int J Agric Sci 1: 311-13.

Publication History

Received 29th May 2018

Revised 26th June 2018

Accepted 05th July 2018

Online 30th July 2018